Use of SWIR Channels for Daytime Sea Surface Temperature Retrieval

Prabhat Koner

ESSIC, UMD, College Park, USA

What is Physical Deterministic SST?

- **Sea Surface temperature retrieval using "Deterministic" inverse method from satellite imager measurement (New initiative and different school of thought).**

- **Most of the satellite derived SSTs are generated using "Regression", *i.e.* Stochastic inverse (complementary of "Deterministic").**

- **"Stochastic" inverse (Bayesian, Regression and/or AI/NN) is based on a set of instances. Where error is treated as definite information for most of the implementations. This is a fundamental flaw.**

- **Deterministic inverse is based on physical model and applied at individual pixel level.**

- **Moreover, a centaury old RT physics is well matured for applying deterministic inverse in satellite retrieval.**

Parametric form of PDSST

Two forms of PDSST: $\mathbf{x}_{pdsst} = \mathbf{x}_{ig} + \mathbf{A}_{inv}\Delta\mathbf{y}_\delta$

a) MTLS for 3 measurements with 2 unknowns

$$\mathbf{A}_{inv} = \left(\mathbf{K}^T\mathbf{K} + \frac{2\log(\kappa)}{\gamma_{snr}^2}\sigma_{end}^2\,\mathbf{I}\right)^{-1}\mathbf{K}^T \qquad \langle\sigma_{end} = [\mathbf{K}\,\Delta\mathbf{y}_\delta]_{lowest}\rangle$$

b) TTLS for 6 measurements with 3 unknowns

$$\mathbf{A}_{inv} = (\mathbf{K}^T\mathbf{K} + \lambda\,\mathbf{I})^{-1}\mathbf{K}^T \qquad \lambda = \begin{cases} -\sigma_{end-1}^2, & r < t \\ \left(\sigma_{end-1}/\log(r)\right)^2, & r \geq t \end{cases}$$

**Analytical error estimation and information content at individual retrieval**

$$\|e\| = \left\|(\mathbf{M}_{rm} - \mathbf{I})(\mathbf{x}_{true} - \mathbf{x}_{ig})\right\| + \|\mathbf{A}_{inv}\|\langle\left\|(\Delta\mathbf{y}_\delta - \mathbf{K}(\mathbf{x}_{true} - \mathbf{x}_{ig}))\right\|\rangle$$

$$\text{DFR} = \text{trace}\,(\mathbf{M}_{rm}); \;\; \mathbf{M}_{rm} = \mathbf{A}_{inv}\mathbf{K}$$

Comparison of MTLS (2 variables) and TTLS (3 variable) using a month of MODIS matchups and EXF

- Increased parametrization of inverse problem has dual benefit as: a) reduces retrieval error and b) Increases information content of retrieval.

- Proposed EXF for complete cloud-free condition is working well as RMSE of TTLS ≈ 0.22 K, which is inherent buoy random error.


November 2015
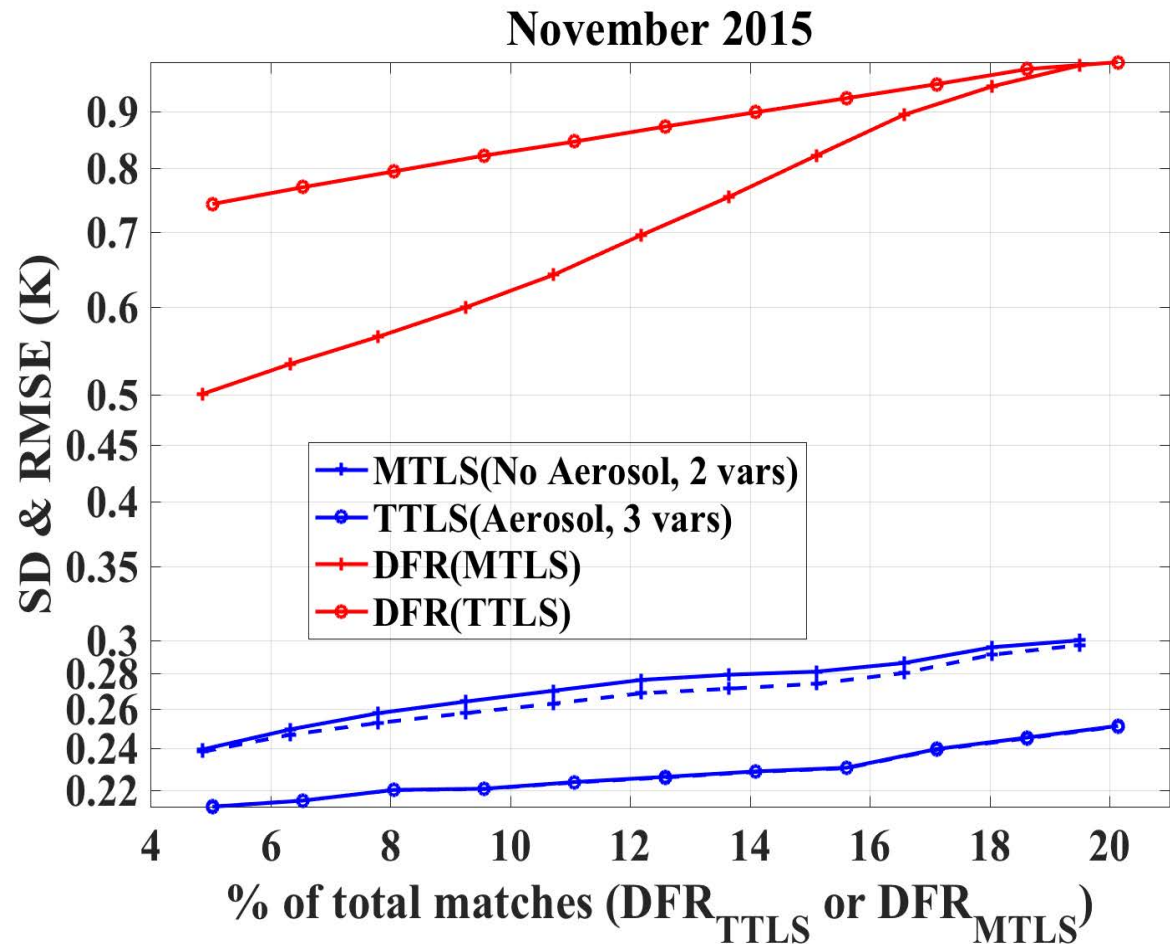
Advantages of PDSST over Prevalent

1. **Substantially reduces SST error by adapting to "local" atmospheric information through NWP (Numerical Weather Prediction) data.**

2. **Ensures the balance between information content and noise of the retrievals: *i.e.* sensitivity is close to 1 when the initial guess (IG) is "far" from truth.**

3. **Unprecedented capability as "Aerosols" can be explicitly included in the forward modeling calculations as well as in the retrieval vector.**

4. **Straightforward option to include both multiple channels and multi-parameter to reduce uncertainty/error in SST.**

5. **Provides meaningful estimates of error and information content analysis at pixel level.**

6. **Automatically adapts to improvements in RT modelling, instrument calibration, improvements in cloud detection, *etc.*, due to case-by-case dynamic estimates of noise using SVD at the solution time.**

1 millions of matchups were studied. PD SST suite increases average data coverage from ~9% to 18% & simultaneously reduction of RMSE from 0.51 to 0.34 K.
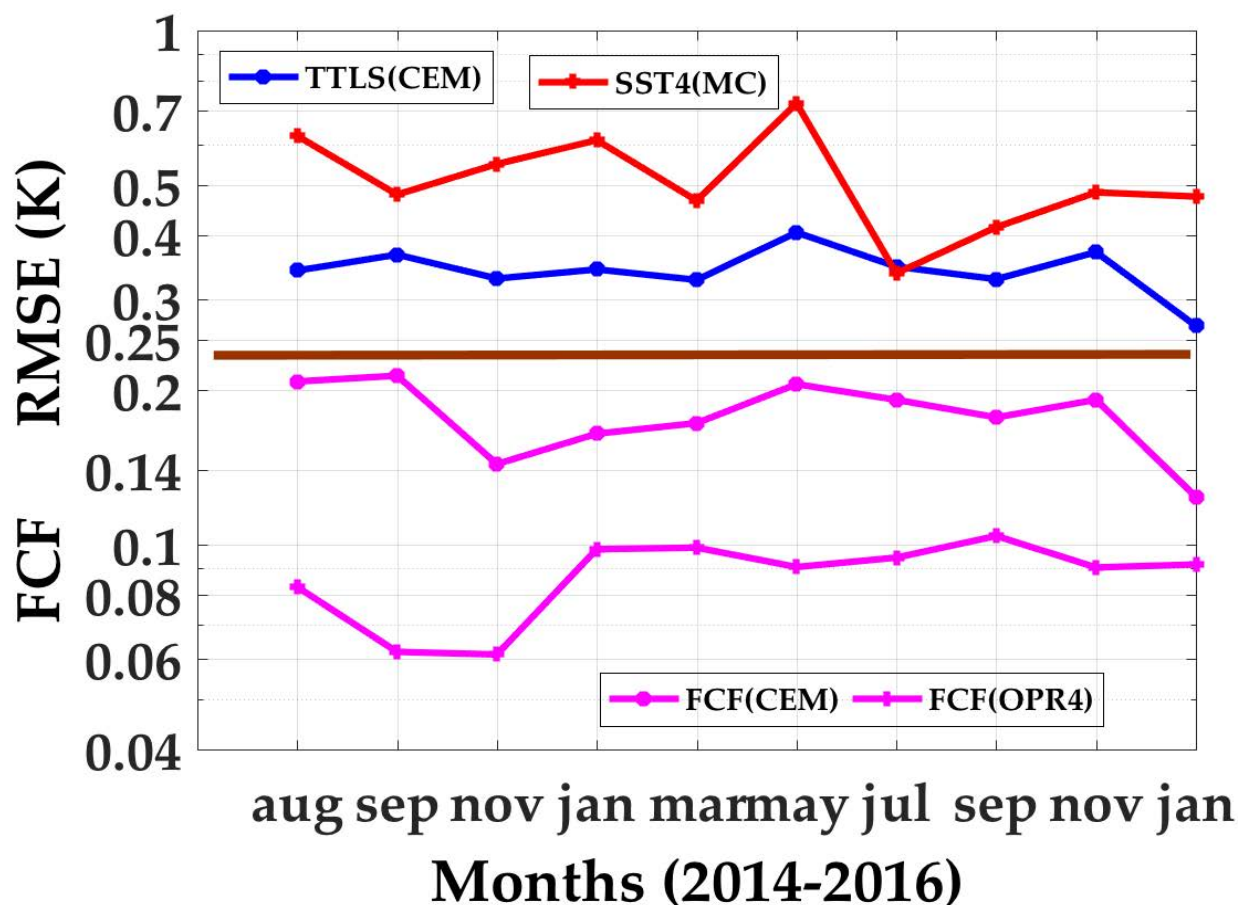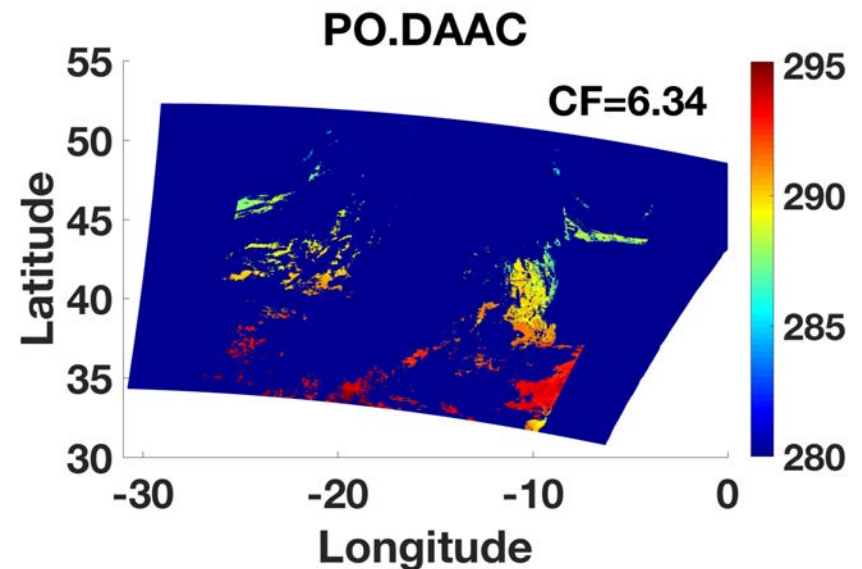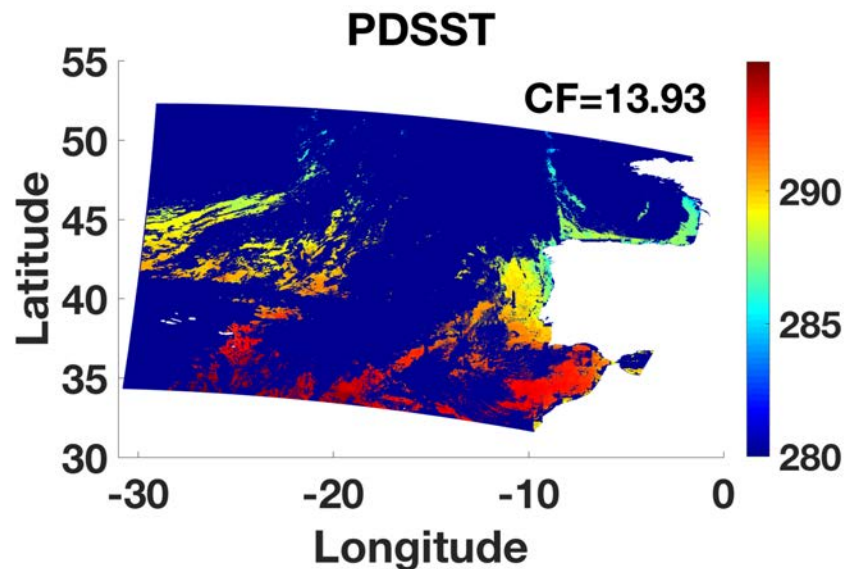

Koner, P.K., and Harris, A. Sea surface temperature retrieval from MODIS radiances using truncated total least squares with multiple channels and parameters, Remote Sensing 2016, 8(9), 725. doi:10.3390/ rs8090725.

No. of Buoy matches: 28

Methods	Match – 1	Match - 2	Match - 3	RMSE (K)
PDSST	-0.14	-0.02	-0.51	0.31
OPR11	1.65	0.17	-0.23	0.97
OPR4	1.22	0.25	-0.25	0.74

As example of cloud leakage by prevalent algorithm, which increased the error statistics.

Dynamic area SSTs: California Coast

Meth.	1	2	3	4	5	6	7	8	9	RMS
PDSST	-0.26	-0.20	0.22	0.28	0.09	-0.01	0.10	-0.03	0.10	
	0.13	-0.05	0.05	0.13	0.05	-0.26	-0.15	0.03	-0.29	
	0.16	0.18	0.07	-0.28	0.00	-0.06	= 24 out of 47			0.16
OPR11	0.01	0.25	0.13	0.08	0.15	0.30	0.17	-0.09	0.44	0.22
OPR4	-0.29	-0.20	0.06	-0.28	-0.33	0.04	-0.13	-0.25	0.00	0.21
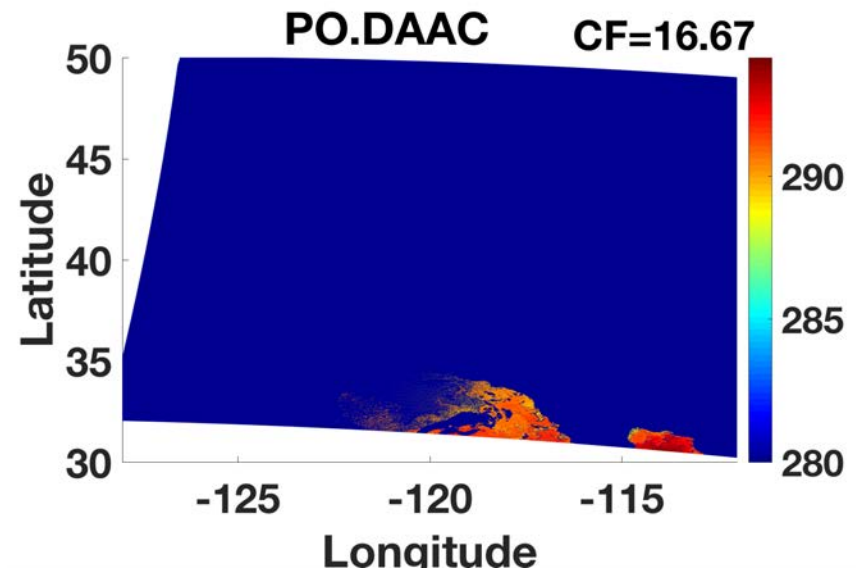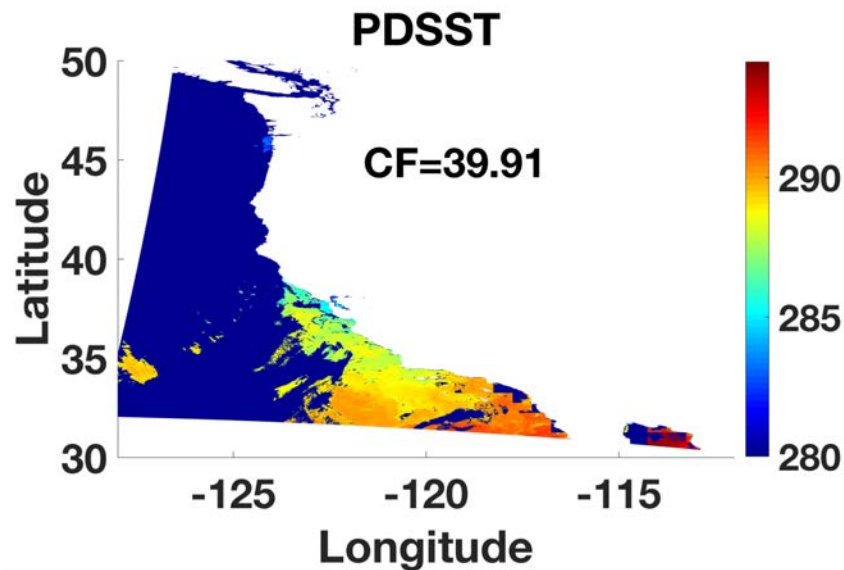
Prevalent algorithm is highly screening the retrieved SST near coastal area, which is most important for oceanic studies.

Indian Ocean SSTs: IIOE-2

Methods	Match - 1	Match - 2	Match - 3	Match - 4	RMSE
PDSST	-0.17	-0.08	0.16	0.05	0.12
OPR11	-0.09	0.26			0.20
OPR4	0.05	0.26			0.19
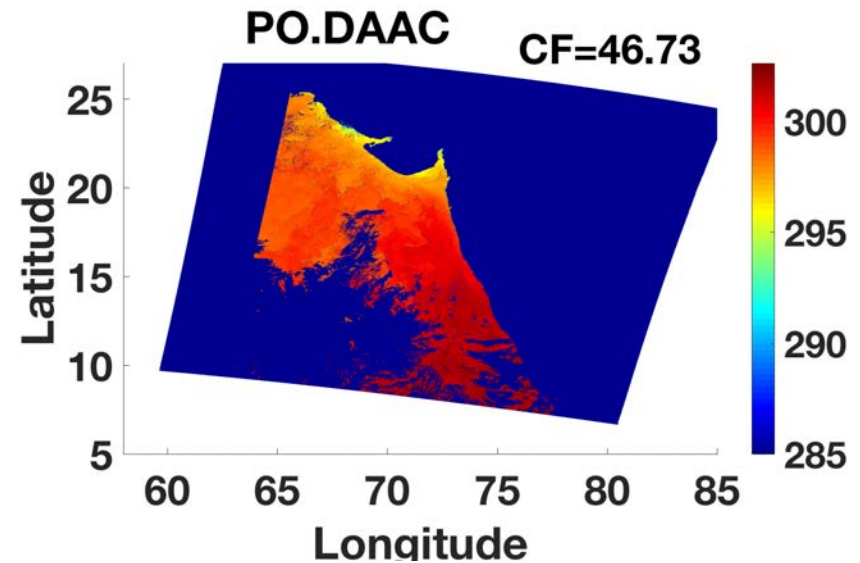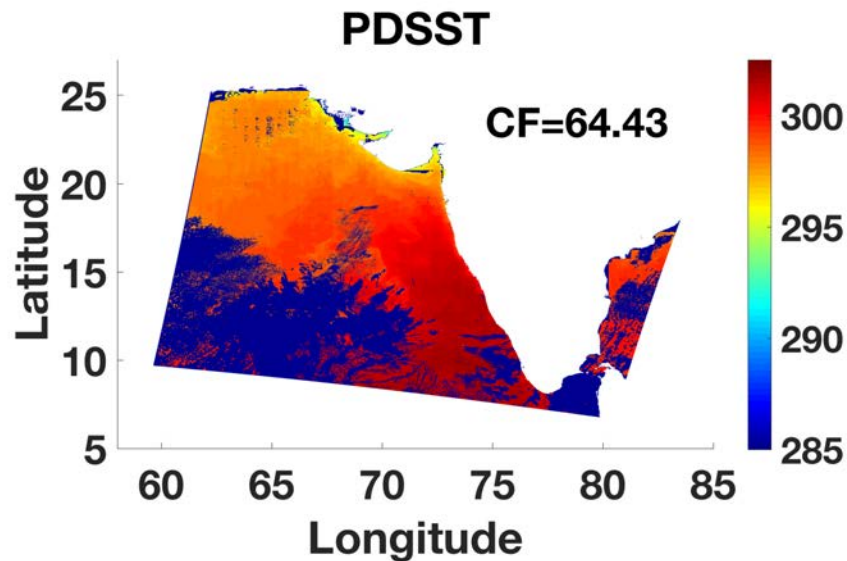
**Prevalent algorithm is totally screened the Bay of Bengal.**

Complete Cloud-free condition is pre-requisite to compare and develop retrieval and cloud detection algorithms

This concept has been published in several peer-reviewed publications, *e.g.* **P. K. Koner et al. Hybrid cloud and error masking to improve the quality of deterministic satellite sea surface temperature retrieval and data coverage, Remote Sens. Environ., vol. 174, p. 266-278, 2016**

$$abs\left(\mathbf{T_b} - \mathbf{T}_{ig} - \mathbf{rtv}_{3.9}\right) \leq 1; \ \mathbf{rtv}_{3.9} = \frac{\mathbf{T}_{3.9}^m - \mathbf{T}_{3.9}^s}{\mathbf{K}_{3.9}^{sst}}$$

Revisiting Split-Window Technique
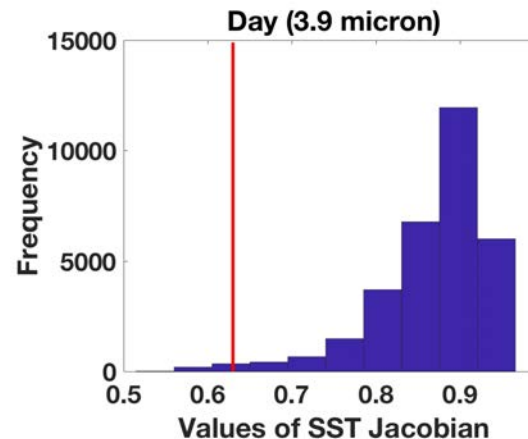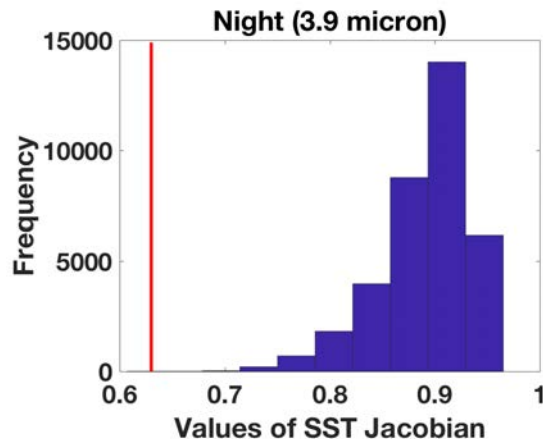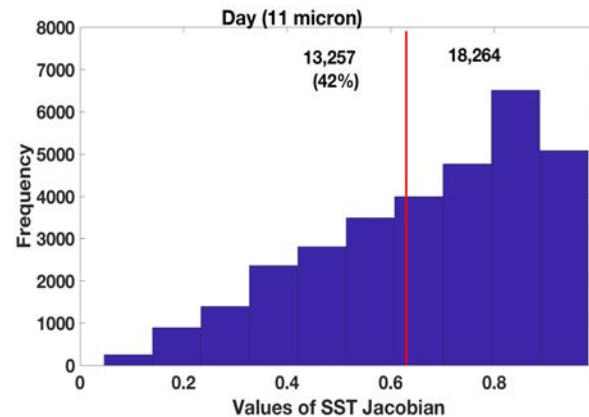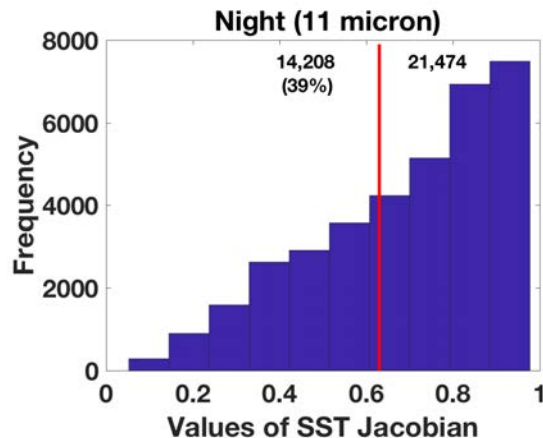
1. SST Jacobian is proportional to transmission.
2. Fundamental assumption for Split window: 11 μm is a window channel.
3. How to define window channel: perhaps penetration depth concept.
4. Quality of SST retrievals using SW method is questionable.

Observations: ~40% measurements of 11 μm below penetration depth: fundamental assumptions doesn't hold. 3.9 μm measurement is must to know SST. Additionally, Planck function 3.9 μm is steeper than that of ~11 μm

Functional Form of Split-Window

$$T_{sw} = a_0 + a_1 T_{11}^m + a_2(T_{11}^m - T_{12}^m)T_{ig} + a_3(T_{11}^m - T_{12}^m)(\sec\theta - 1)$$

A hypothetical Experiment is made using a month of MODIS-A match up data, replacing T_{ig} by T_b and EXF.

Operational SST producers often employed the piece-wise regression using multiple coefficients sets to reduce these errors, but the quality of these retrievals is still questionable
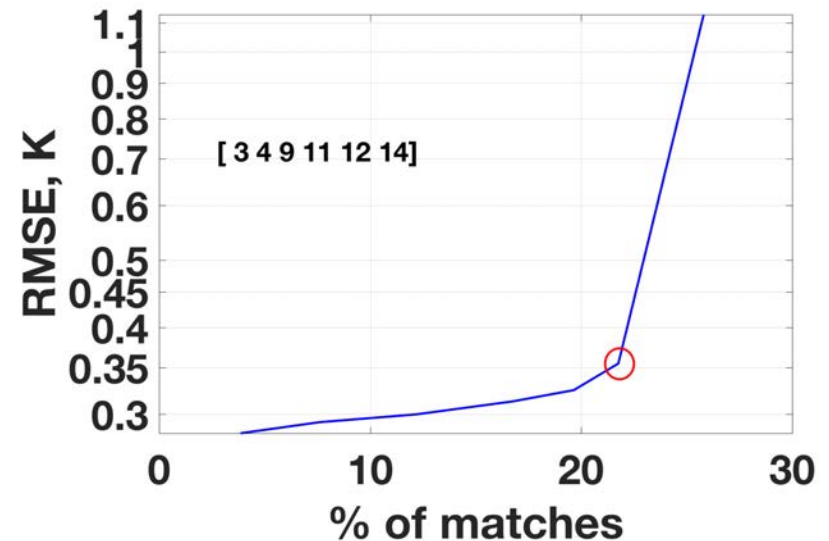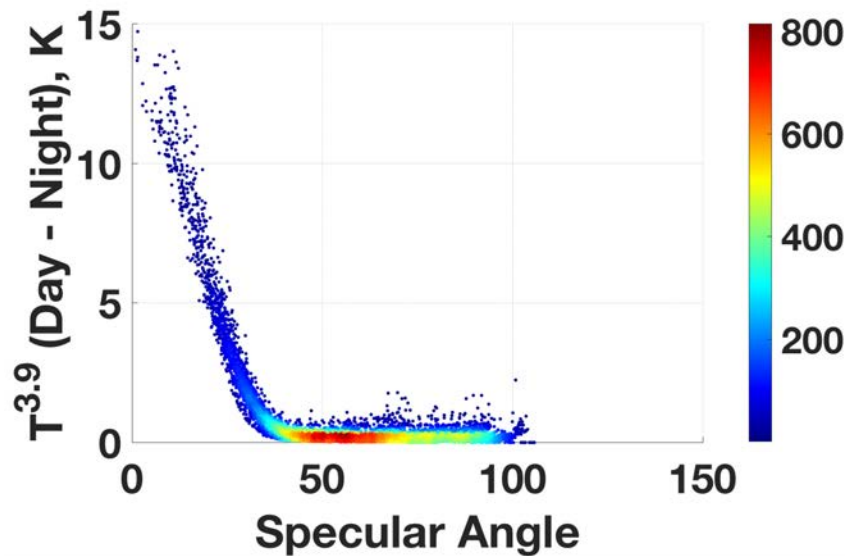

July 2015
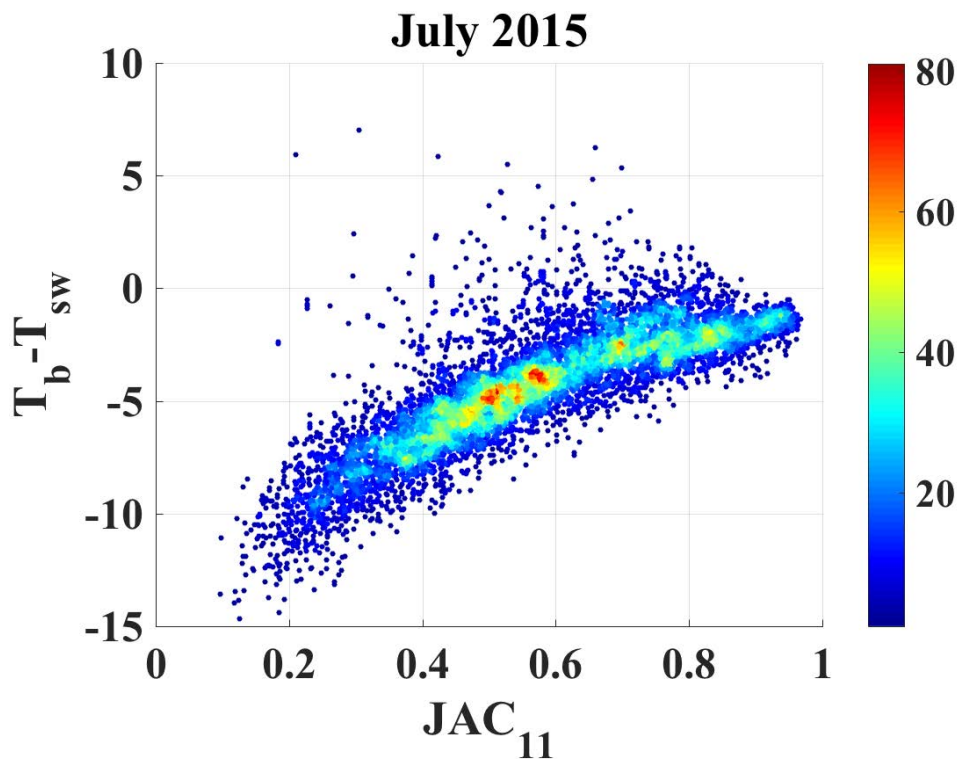
CRTM Day time simulation

$$abs\left(\mathbf{T}_b - \mathbf{T}_g - \mathbf{T}_{rtv}^{3.9}\right) < \frac{0.75}{K_{sst}^{3.9}} \; ; \mathbf{T}_{rtv}^{3.9} = \frac{T_m^{3.9} - T_s^{3.9}}{K_{sst}^{3.9}}$$

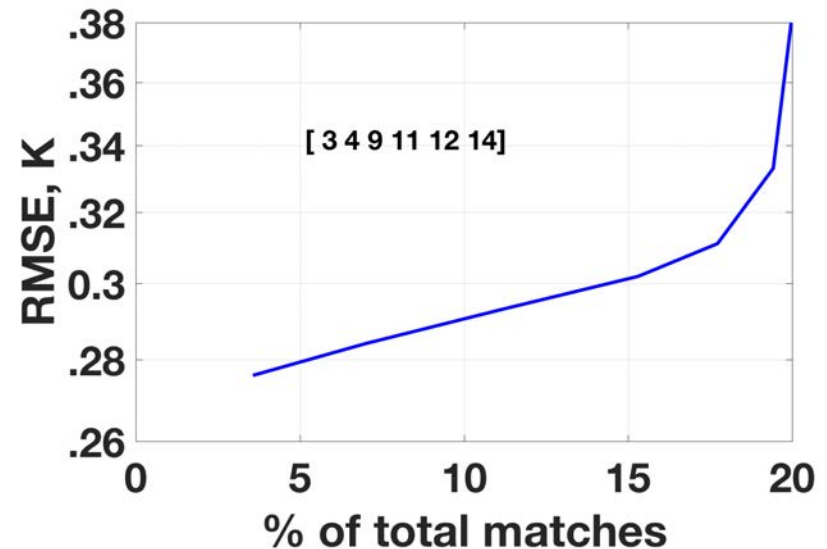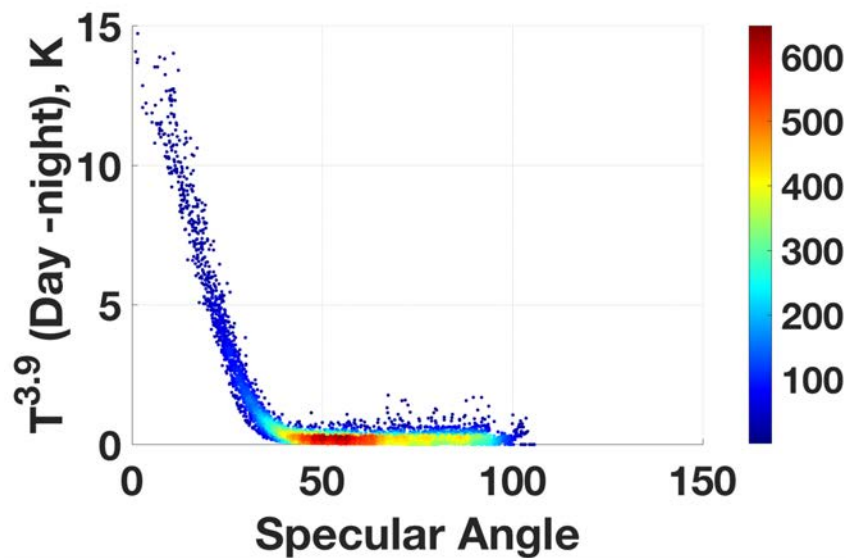$$\theta_v = \cos(\theta_{slz})\cos(\theta_{stz}) + \sin(\theta_{slz})\sin(\theta_{stz})\cos(\theta_{raz})$$
$$\theta_{spec} = 180\cos^{-1}(\theta_v)/\pi$$

1. Specular component of CRTM is satisfactory.
2. Ocean surface is quasi-specular and BRDF component in CRTM has to be improved.

CRTM Day time simulation

$$abs\left(\mathbf{T}_b - \mathbf{T}_g - \mathbf{T}_{rtv}^{3.9}\right) < \frac{0.75}{K_{sst}^{3.9}} \ \& \ dd(T^{3.9}, T^{11}) < 3$$

1. Some measurements are discarded due to deficiency of CRTM.
2. ~20% of matches in cloud-free set is much higher than operational of 7% (QL=5).
3. Nighttime SD~0.22K and bias ~0.17K, whereas Daytime SD ~0.3, which is comparable $\sqrt{(0.22^2 + 0.17^2)} = 0.28$

GOES-13 daytime SST retrieval
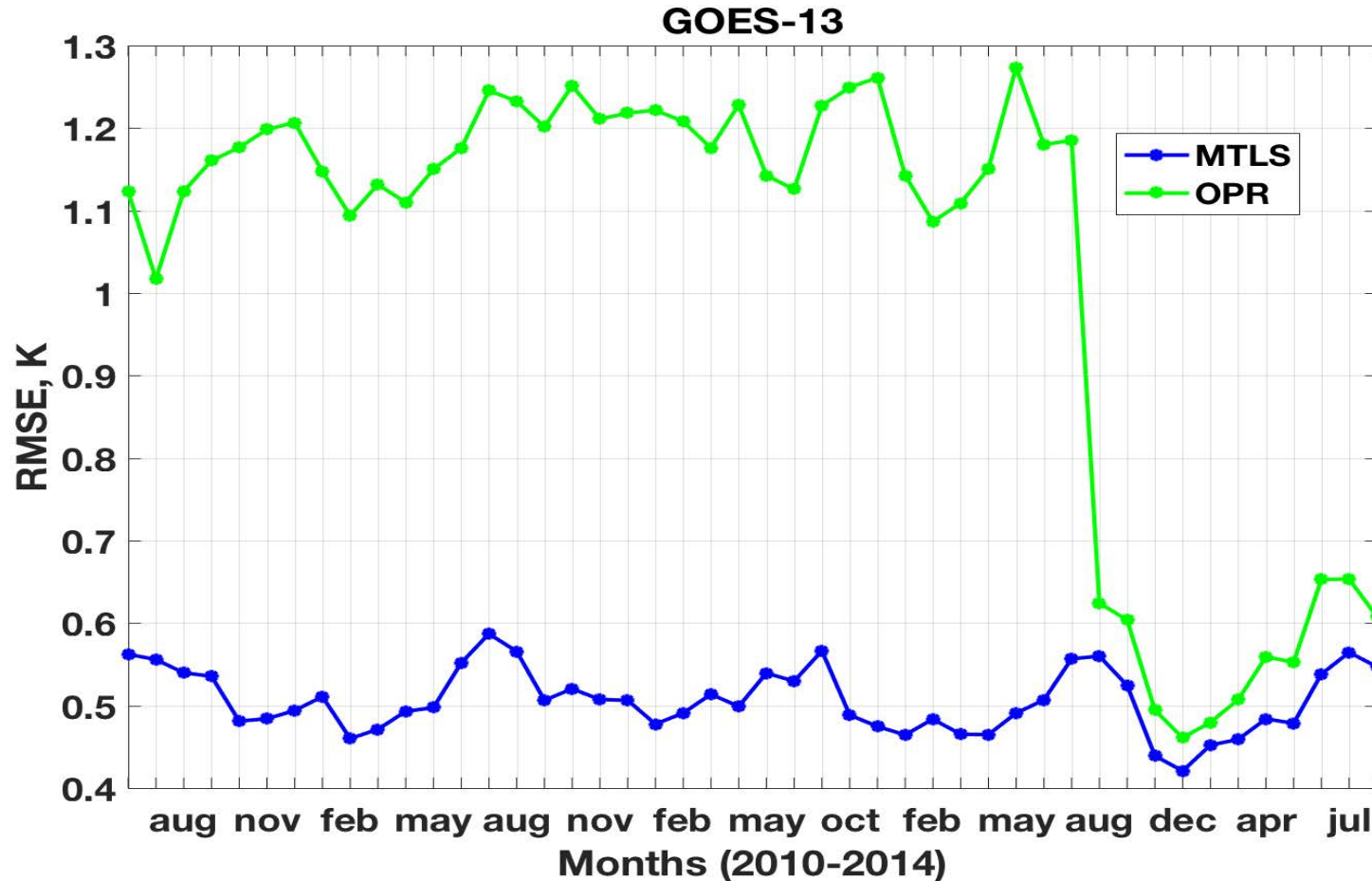
Prabhat K. Koner, Andy R. Harris & Eileen Maturi, Hybrid cloud and error masking to improve the quality of deterministic satellite sea surface temperature retrieval and data coverage, Remote Sensing Environment, vol. 174, p. 266-278, 2016.

Conclusions:

- 2-3 times information gain is achievable using PDSST as compared to presently implemented stochastic retrievals.
- Information retrieval from satellite data even more for dynamic areas, where need the most.
- Additionally, our other work on simulated profile retrievals from satellite sounder measurement using deterministic retrieval shows an outstanding improvement.
- Perhaps, it is time to think to paradigm-shift in satellite inverse problem to open a new door for Geo-science research.

Thank You

Questions?

Regression based Retrieval

$$SW_{org} = a_0 + a_1 T^{11} + a_2(T^{11} - T^{12}) + a_3 T_b(T^{11} - T^{12}) + a_3(\sec(\theta_{stz} - 1))(T^{11} - T^{12})$$

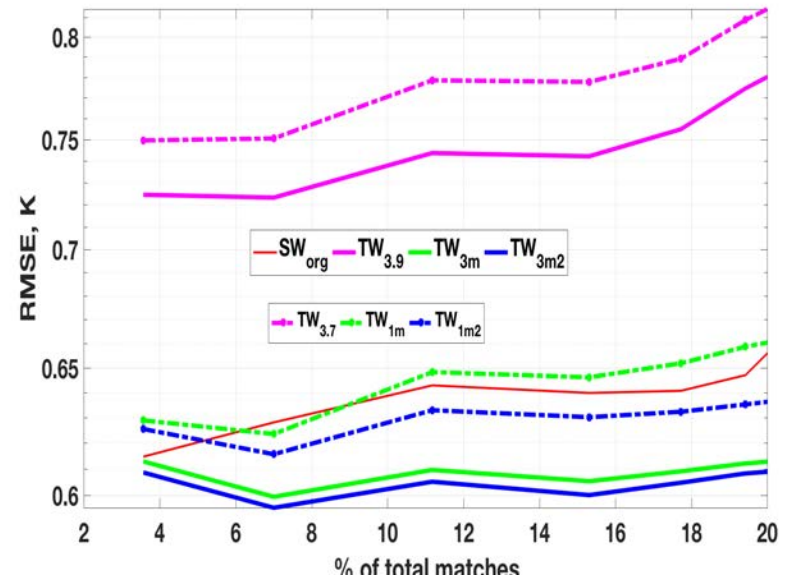$$TW_{3.9} = a_0 + a_2 T^{3.9} + a_1 T^{11} + a_2(T^{11} - T^{12}) + a_3(\sec(\theta_{stz} - 1))(T^{11} - T^{12})$$

$$TW_{3.7} = a_0 + a_2 T^{3.7} + a_1 T^{11} + a_2(T^{11} - T^{12}) + a_3(\sec(\theta_{stz} - 1))(T^{11} - T^{12})$$

$$TW_{3m} = a_0 + a_2 T^{3.9} + a_1 T^{11} + a_2(T^{11} - T^{12})$$
$$+ a_3(\sec(\theta_{stz} - 1))(T^{11} - T^{12})$$
$$+ a_4 \theta_{spec}(T^{3.9} - T^{11})$$

$$TW_{3m2} = a_0 + a_2 T^{3.9} + a_1 T^{11} + a_2(T^{11} - T^{12})$$
$$+ a_3(\sec(\theta_{stz} - 1))(T^{11} - T^{12})$$
$$+ a_4 \theta_{spec}(T^{3.9} - T^{11}) + a_5 \theta_{spec}(T^{3.9} - T^4)$$

$$TW_{3m} = a_0 + a_2 T^{3.7} + a_1 T^{11} + a_2(T^{11} - T^{12})$$
$$+ a_3(\sec(\theta_{stz} - 1))(T^{11} - T^{12})$$
$$+ a_4 \theta_{spec}(T^{3.7} - T^{11})$$

$$TW_{1m2} = a_0 + a_2 T^{3.7} + a_1 T^{11} + a_2(T^{11} - T^{12})$$
$$+ a_3(\sec(\theta_{stz} - 1))(T^{11} - T^{12})$$
$$+ a_4 \theta_{spec}(T^{3.9} - T^{11}) + a_5 \theta_{spec}(T^{3.7} - T^4)$$

Extra

May 2017

December 2017